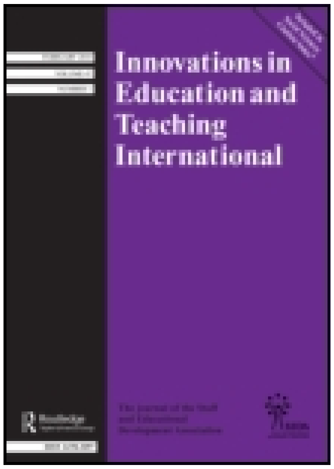
This article was downloaded by: [Radboud Universiteit Nijmegen]
On: 03 December 2014, At: 05:51
Publisher: Routledge
Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



Innovations in Education & Training International
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/riie19

THE ADAPTIVELY CONTROLLED INSTRUCTION OF A TRANSFORMATION SKILL

Gordon Pask [a] & Brian Lewis [b]
[a] System Research Limited
[b] University of London Institute of Education

Published online: 09 Jul 2006.

To cite this article: Gordon Pask & Brian Lewis (1967) THE ADAPTIVELY CONTROLLED INSTRUCTION OF A TRANSFORMATION SKILL, Innovations in Education & Training International, 4:2, 74-86, DOI: 10.1080/1355800670040202

To link to this article: http://dx.doi.org/10.1080/1355800670040202

PLEASE SCROLL DOWN FOR ARTICLE

Taylor & Francis makes every effort to ensure the accuracy of all the information (the "Content") contained in the publications on our platform. However, Taylor & Francis, our agents, and our licensors make no representations or warranties whatsoever as to the accuracy, completeness, or suitability for any purpose of the Content. Any opinions and views expressed in this publication are the opinions and views of the authors, and are not the views of or endorsed by Taylor & Francis. The accuracy of the Content should not be relied upon and should be independently verified with primary sources of information. Taylor and Francis shall not be liable for any losses, actions, claims, proceedings, demands, costs, expenses, damages, and other liabilities whatsoever or howsoever caused arising directly or indirectly in connection with, in relation to or arising out of the use of the Content.

This article may be used for research, teaching, and private study purposes. Any substantial or systematic reproduction, redistribution, reselling, loan, sub-licensing, systematic supply, or distribution in any form to anyone is expressly forbidden. Terms & Conditions of access and use can be found at http://www.tandfonline.com/page/terms-and-conditions

THE ADAPTIVELY CONTROLLED INSTRUCTION OF A TRANSFORMATION SKILL

GORDON PASK AND BRIAN LEWIS

System Research Limited

University of London
Institute of Education

Abstract: A keyboard skill is described for which two different (and partly conflicting) rules of correspondence exist between the six stimulus lamps and the six response keys. At any given trial, a subset of three stimulus lamps is illuminated, and an orientation signal tells S which rule of correspondence he must apply. In the main experimental condition, the skill was instructed by an adaptive machine which (a) varied the relative frequency with which the two rules were selected, and (b) simplified certain problems by illuminating fewer lamps. In the first control condition, facility (a) was deleted. In the second control condition, facilities (a) and (b) were *both* deleted. The results show that the fully adaptive condition produced faster learning than the first control condition, and the latter produced faster learning than the second control condition. Some additional analysis suggests that different subjects learned the skill in different ways, and that learning is more efficient if the conflicting rules of correspondence are rehearsed in parallel (rather than sequentially).

INTRODUCTION

THIS paper describes an experiment in which a " transformation " or " code application " skill is instructed by an adaptive teaching machine M (experimental condition A), and also by degenerate programs obtained by deleting certain logically crucial features of the adaptive device (experimental conditions B and C). The complete adaptive program yields a higher rate of acquisition of this sort of skill than either of the degenerate but otherwise plausible alternative modes of instruction, and the coupled man-machine system is stable whilst the subject is learning.

The adaptive teaching strategies in M differ in a few particulars from the strategies used in other teaching devices (Pask 1958, 1960, 1961, 1964; Pask and Lewis 1964; Lewis 1963a, 1963b), or in adaptive aids to performance (Pask 1957; Lewis 1963c), or in adaptively-controlled testing systems (Pask 1963). Since these differences are slight and since, in any case, they mainly affect the initial trials in the experiment, the reported results are broadly comparable with more recent findings (Pask 1965a, 1965b, 1966; Lewis and Pask 1965; Pask and Mallen 1966).

THE NATURE OF TRANSFORMATION SKILLS

In real-life situations, there are many occasions on which it is necessary to switch hurriedly from one mode of behaviour to another. For example, a motorist repeatedly has to decode and act upon sudden and unpredictable signals. If a child's ball rolls out into the middle of the street, this heralds a particular kind of danger for which a particular kind of avoidance action may be needed. Thus ball-followed-by-child might require one type of avoiding action, and ball-without-child might require another. The point to be noticed is that both of these avoiding actions may be already well-learned, in the sense that the motorist knows perfectly well how to brake and swerve in various directions. His problem is to recognise, on any given occasion, the *type* of avoiding action required—and to perform it as quickly as possible.

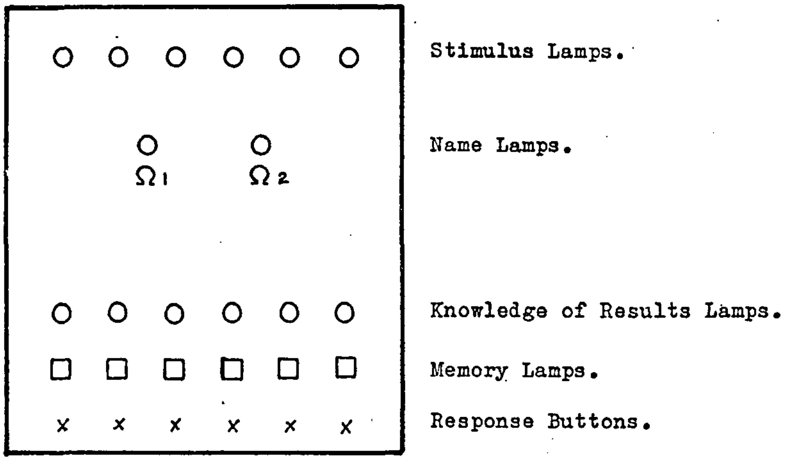
In abstract terms, the motorist must apply some already learned code to a stimulus configuration in order to generate, or transform it into, a suitable pattern of responses. In cases of this kind, emphasis is placed on the rapid selection and application of appropriate transformation rules (one for the ball-plus-child and another for the ball-without-child) and the overall skill can be described as a *transformation* or *code application* skill.

Such skills are components of many different behaviours. To say that a person is a fluent conversationalist, for instance, or a well-coordinated footballer, implies that he is able to select appropriate transformation rules, rapidly and at short notice, for dealing with a wide variety of often unpredictable occurrences. Many other examples could be cited.

LABORATORY REALISATIONS

General requirements

The subject (S), who performs such a skill in the pure form suitable for laboratory use, is given a set of transformations $\Omega_1, \Omega_2, \ldots \Omega_i, \ldots \Omega_n$—each of which defines a particular relationship between a stimulus pattern and a response pattern. Before the experiment begins, S knows and may even have overlearned the transformations. At a particular trial he is presented with a stimulus, x (in the present case this is a visually displayed signal), and the name, i, of the transformation Ω_i required. In the experiment under discussion only two transformations are used, so $i = 1$ or 2, and the " naming " operation simply tells S to apply Ω_1 or Ω_2 as the case may be. S is required to



The Knowledge of Results lamps and the Memory lamps are in one to one correspondence with the Response buttons.

DIAGRAM 1. Display and Response Facilities transform the stimulus x—*i.e.*, to produce $\Omega_i(x)$ to the best of his ability, and to do so within a limited time interval δt. He indicates whatever he believes $\Omega_i(x)$ to be by making a response, y. If the pacing restriction (to produce y within δt after the onset of stimulus x) is applied, then x poses a problem in the context of Ω_i that is correctly solved by the correct response $y = \Omega_i(x)$. Without a suitable pacing restriction, the task is trivial.

Experimental equipment and method

In the present experiment, S had to learn how to deal with stimuli consisting of a subset of $m = 3$ illuminated lamps selected from the row of stimulus lamps in the display of Diagram 1.

There are just six possible stimulus configurations (the $m = 3$ subset of patterns in Diagram 2). These are presented at $\Delta t = 8$ seconds apart, in a sequence that is random apart from the constraint that each configuration occurs with equal frequency in any sub-sequence of twelve trials. The stimuli are presented in the context of the pair of transformations Ω_1 and Ω_2 shown in Diagram 3. At any given trial, just one of these is named by the illumination of one of the two " naming " lamps in Diagram 1.

If π_i denotes the probability of selecting Ω_i at any given trial, then one terminal objective is to select the Ω_i equi-probably and in an unpredictable order. When $i = 1$ or 2, the equi-probability requirement is met by making $\pi_1 = \pi_2 = \pi_i = 0{\cdot}5$. And if this condition holds at *each* new trial successive selections are stochastically independent and, in this sense, unpredictable (Feller 1957).

Since Ω_1 and Ω_2 are one-to-one correspondences (relating the stimulus lamps to the lower row lamps in the display or, equivalently, to the response buttons), any correct response will contain just m different response selections (*i.e.*, m different response buttons will be pressed by the subject). To count as correct, the entire response construction y must equal $\Omega_i(x)$ in all m selections, and it must be produced within an interval of $\delta t = 4{\cdot}5$ seconds after the onset of x. No credit is given for a partly correct response construction. However, the *order* of button pressing is irrelevant and S need not press the response buttons simultaneously.

To avoid some extraneous " distracting " effects of rapid pacing, S is provided with an externalised short-term memory facility (the row of memory lamps in diagram 1). Each response button, when pressed, energises a lock relay which

x_1	x_2	x_3	x_4	x_5	x_6	
abc	acd	ace	bdf	bef	cef	m = 3
ac	ad	ce	bd	bf	ef	m = 2
a	b	c	d	e	f	m = 1

DIAGRAM 2. Stimulus Structure.

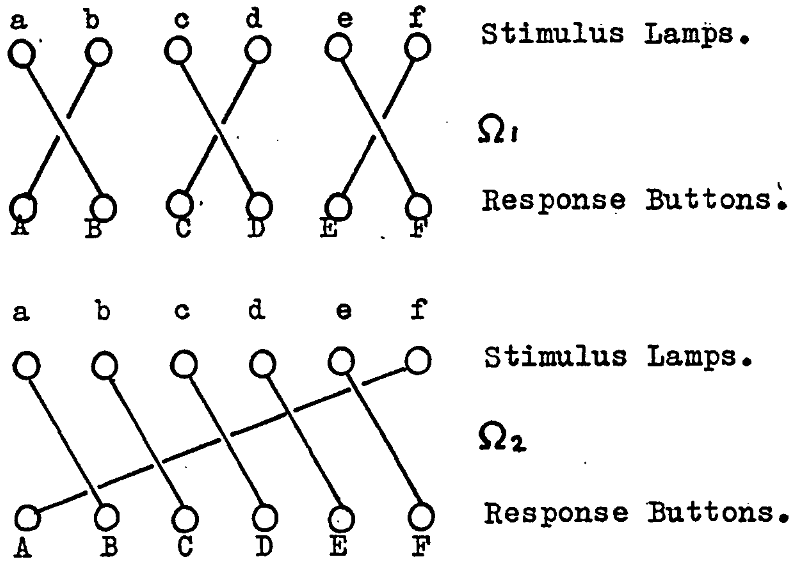


DIAGRAM 3. Transformation Rules

remains energised until 2·5 seconds after the end of δt. This illuminates the memory lamp located immediately above the response button concerned, and reminds S that he did in fact press it.

S is also provided with knowledge of results. The stimulus lamps displaying x remain illuminated throughout δt, the 4·5 seconds interval allowed for producing a response. At the end of δt, the response buttons are de-activated, and an image of $\Omega_i(x)$ is displayed for 2·5 seconds by illuminating a subset of m of the knowledge of results lamps in Diagram 1. This image is displayed immediately above the memory lamp presentation of y, so that S can compare his actual response with the correct response. Since $\delta t = 4{\cdot}5$ seconds, this feedback signal terminates after $4{\cdot}5 + 2{\cdot}5 = 7$ seconds, so there is a one-second rest interval between the offset of the feedback and the onset of the next stimulus.

The discussion has so far considered only those terminal conditions that will be dealt with by a subject who has learned the skill by, say, $n = T$ trials. To convert this specification into a terminal performance criterion, it is additionally necessary to stipulate a level of correct response probability contingent upon each of the transformations, and sustained over a series of (in this case) twenty-four trials. If $p_i(n)$ is the probability that S will produce a correct response $y = \Omega_i(x)$, given x and i (where it is understood that $p_i(n)$ is computed over all those occasions, during the previous twenty-four trials, on which Ω_i was selected), S was deemed to have reached criterion performance after T trials, where T is the value of n for which *both* $p_i(n)$ achieve (or exceed) the value 0·9. This condition can be minimally expressed as:

$$p_1(T) = p_2(T) = p_i(T) = 0{\cdot}9$$

It demands that S should reach 90 per

cent accuracy (averaged over the twenty-four previous trials) on both transformations concurrently. The experiment terminates at the value of $n = T$ for which this is true, provided that the following two conditions have *also* held for twenty-four trials:

$$\pi_1(T) = \pi_2(T) = \pi_i(T) = 0{\cdot}5$$
$$m_1(T) = m_2(T) = m_i(T) = 3.$$

The first of these ancillary conditions requires that the selection of the Ω_i should have been both equi-probable and unpredictable. The second condition asserts that none of the problems should have been cued or " simplified " (in the manner about to be discussed). It is worth remarking that once the above three conditions were met, they could almost invariably be maintained for at least fifty further trials. After this, performance tended to deteriorate through boredom and fatigue, chiefly because there was nothing left for S to learn.

The values of δt and Δt have been chosen so that if a novice is presented with a sequence of stimuli under the conditions that prevail when $n = T$, then he is unable to perform the skill successfully and is also unable to learn to perform it (unless there are memorising facilities of a sort that are explicitly disallowed). Hence, in order to teach the skill, it is necessary to present a program wherein, for values of n less than T, the values of $\pi_i(n)$ and $m_i(n)$ depart from $\pi_i(T)$ and $m_i(T)$. Any variation of $m_1(n)$ or $m_2(n)$—determined separately for the " sub-skills " engendered by the transformations Ω_1 and Ω_2—constitutes a simplification of the " subskill " concerned. It has the effect of reducing the perceptual and cognitive load upon the subject in respect of that particular subskill, and is achieved by selecting stimuli from the $m = 1$ row or the $m = 2$ row of Diagram 2 (rather than the $m = 3$ row). Any variation of $\pi_i(n)$ alters the relative frequency with which the two subskills are rehearsed. This could help or hinder S, depending upon which subskill is causing him the greater concern. Conditions A, B, and C in the present report correspond to different programs, in the sense of different simplification and alternation strategies. The merits of these strategies will be compared in terms of T (the number of trials needed for S to reach the terminal condition). Since Δt is constant, the comparison of T values is an indication of relative acquisition rates.

METHODS OF INSTRUCTION

In condition A, the subject is instructed by an adaptive control mechanism, M, that modulates the simplification and the alternation of the subskills as a function of the subject's proficiency at the nth trial. The machinery is shown in Diagram 4, and its organisation in Diagram 5.

First, the subject's response, $y(n)$, at the nth trial, is compared with the correct response $\Omega_{i(n)}[x(n)]$ that *should* have been made to the stimulus, $x(n)$, presented at the nth trial. This comparison yields a correct response score:

$$\sigma_i(n) = +1 \quad \text{if } y(n) = \Omega_{i(n)}[x(n)], \text{ and}$$
$$\sigma_i(n) = -1 \quad \text{if } y(n) \neq \Omega_{i(n)}[x(n)].$$

The subject's proficiency with respect to subskill i at the nth trial, $\rho_i(n)$, is indexed as $\Sigma\,\sigma_i(n)$—where the $\sigma_i(n)$ are aggregated over all trials for which the ith subskill has been selected.

The simplification strategy in M is an adjustment of m_i according to the value of $\rho_i(n)$ as follows:

$$m_i(n) = 1 \quad \text{if } 8 > \rho_i(n)$$
$$m_i(n) = 2 \quad \text{if } 16 \geqslant \rho_i(n) \geqslant 8$$
$$m_i(n) = 3 \quad \text{if } \rho_i(n) > 16$$

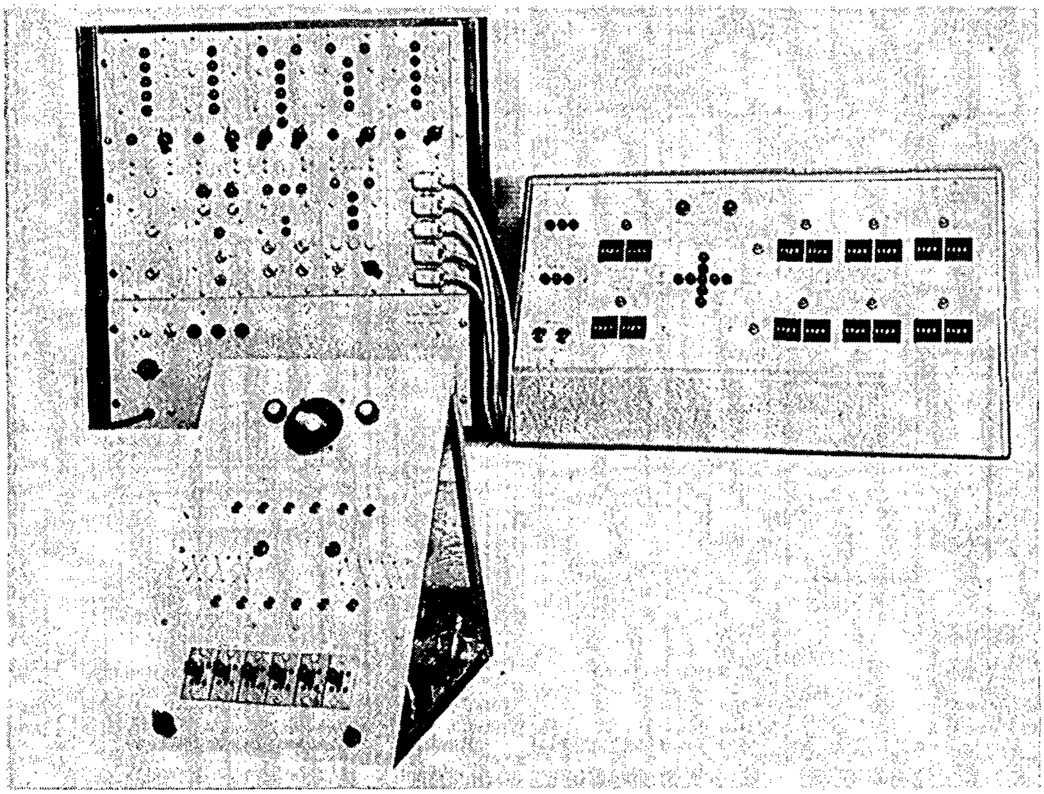


DIAGRAM 4. Display and Response Board, Recording Console and Adaptive Machine

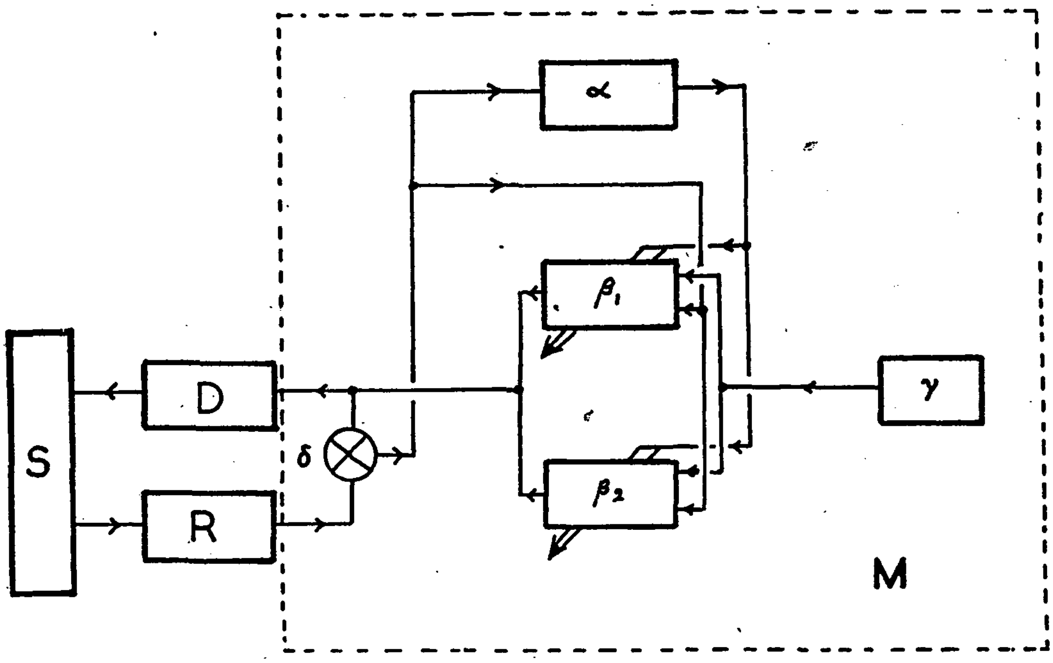
. . . where, for mechanical reasons, there are limits on $\rho_i(n)$ so that $32 > \rho_i(n) > 0$.

Since $\rho_i(n) = 0$ at the commencement of the experiment, $m_i(n) = 1$. So the program starts by posing simple one-lamp problems. When $\rho_i(n)$ reaches 8, M switches to two-lamp problems, under transformation Ω_i, and three-lamp problems are introduced when $\rho_i(n)$ exceeds 16. This very primitive simplification strategy is intended to maintain the subject's attention by locating a difficulty level (with respect to each subskill separately) that adequately loads his short-term memory. It is the precursor of the far less primitive maximum loading procedures that have been embodied in other systems.

The alternation strategy of M is a function of a pair of variables, namely:

$$z(n) = \rho_1(n) - \rho_2(n), \text{ and}$$
$$\theta(n) = \sum_i \sum_n m_i(n).\ \sigma_i(n)$$

The first of these variables, z(n), indicates the subject's relative success in dealing with subskills 1 and 2. Its value can range from +16 to −16 (according to whether S is better or worse at subskill 1) but, for purposes of contributing to



S = Subject. D = Display. R = Response.
α = Alteration Strategy unit determining i(n).
γ = Arbitrary sequence of unsimplified problems.
δ = Comparator and Averager for obtaining proficiency measure.
β_1 and β_2 = Simplification Strategy units for Subskill 1 and Subskill 2, determining $m_1(n)$ and $m_2(n)$.

DIAGRAM 5. Organisation of Subject, M, System

the adjustment of π_i, just five equal-interval categories of z are distinguished. These are designated z_j (j = 1 to 5), where j = 3 indexes the middle-range category for which the individual proficiency scores $\rho_1(n)$ and $\rho_2(n)$ are approximately equal.

The second variable, θ(n), is an overall weighted proficiency measure, which increases from zero to sixty-three (a mechanically imposed limit) as S becomes proficient. For purposes of contributing to the adjustment of π_i, just four equal-interval categories of θ (designated θ_1 to θ_4) are distinguished.

To determine the probability, $\pi_1(n)$, of presenting S with Ω_1 at the nth trial, M reads out the appropriate probability entry in the matrix shown in Diagram 6 below.

Since $\pi_1(n) = 1 - \pi_2(n)$, the matrix effectively determines the values of both the $\pi_i(n)$ probabilities. Either value can be interpreted as the bias applied to an

" electronic coin " that is tossed at each trial to determine the next (nth) value of i. (Electrically, the coin-tossing is an initial part of each trial, since it not only decides the value of i(n), but also sets up the comparators and averagers used in M.) Continuous variation of each $\pi_i(n)$ is approximated by a set of discrete values (those shown in the Diagram 6 matrix), one of which is uniquely determined by the conjoint values of z(n) and θ(n). The value given by the matrix is presented as a bias to the probabilistic circuit which selects one subskill or the other (*i.e.*, one transformation or the other) for the nth trial.

θ(n) category:	θ_1 poor	θ_2 below average	θ_3 above average	θ_4 good	
z(n) category					*z(n) interval*
z_1	·97	·90	·10	·03	$z(n) > +10$
z_2	·85	·75	·25	·15	$+10 > z(n) > +4$
z_3	·50	·50	·50	·50	$+4 > z(n) > -4$
z_4	·15	·25	·75	·85	$-4 > z(n) > 10$
z_5	·03	·10	·90	·97	$-10 > z(n)$

DIAGRAM 6. Matrix showing values of π_1 for conjoint values of θ(n) & z(n)

The object of this alternation strategy is to present the *novice* with a situation in which he most often rehearses the subskill at which he is most proficient, but to present the *skilled subject* with the converse situation in which he most often rehearses the subskill that he finds hardest.

Provided that S is able to learn, these simplification and alternation strategies ensure convergence to a state of affairs that will satisfy the terminal criterion of performance. As learning proceeds, $\rho_i(n)$ increases until $\rho_i(n) \to 0{\cdot}9$ under conditions in which $m_i(n) = 3$. Also, if $\rho_1(n) \doteqdot \rho_2(n)$, so that z(n) is in z_3, then $\pi_1(n) = \pi_2(n) = 0{\cdot}5$. Finally, if S achieves high values of $\rho_1(n)$ and $\rho_2(n)$, when $m_1(n) = 3$ and $m_2(n) = 3$, then θ(n) is in θ_4.

There is, of course, nothing sacrosanct about the matrix values given in Diagram 6. A fairly wide range of values have similar (and, in some cases, slightly more rapid) convergence properties. The values actually chosen happen to be the ones that the available equipment could most readily realise.

To obtain condition B, the simplification strategy in M is left unaltered, but the alternation strategy is replaced by the rule $\pi_1(n) = \pi_2(n) = 0{\cdot}5$. This can be interpreted as a fixed bias of 0·5 applied to the probabilistic circuit, regardless of S's performance.

In condition C, the simplification strategy is also deleted from the system. S is therefore presented with three-lamp problems from the outset. In this condition, the pacing restrictions prevent S from being able to cope with subskill alternation, so he is first instructed on subskill 1 alone — until he achieves a (0·83) proficiency criterion of ten correct responses over twelve successive trials. After this, he is instructed on subskill 2 alone, to the same proficiency level. Finally, the subskills are alternated (so that $\pi_1(n) = \pi_2(n) = 0{\cdot}5$) until S achieves the criterion $p_1(n) = p_2(n) = 0{\cdot}9$ — sustained, in this case, over twenty-four trials.

The 0·83 proficiency level for individual subskills is not arbitrary. It was empirically determined (using another twenty subjects) as the level that was most likely to minimise the overall number of trials to criterion. In this sense, condition C approximates to being the best non-adaptive (or " minimally adaptive ") counterpart of the adaptive programs run in conditions A and B.

The experimental prediction is that $T_C > T_B > T_A$, or that the rate of acquisition will be greater in condition A than in condition B, and greater in condition B than in condition C. To test this hypothesis, values of T were determined for three matched groups of twenty subjects, one group being assigned to each of the conditions. In addition, more detailed records were made, using the console in Diagram 4, for a randomly chosen sub-sample of four subjects in the condition A group.

Subjects used

The subjects used for this experiment had come to the laboratory to take part in a group concept-learning experiment (Pask 1962; Lewis and Pask 1964). They had all previously experienced mechanised experiments in the same laboratory. They came from a pair of populations, about half being members of the MENSA Society, and the rest being a fairly homogeneous group of local volunteers. The majority of subjects were under thirty years of age, about two-thirds of them were males, and they were partitioned (on the basis of age, sex, and population type) into three approximately-matched groups of twenty.

The experimental session was preceded by roughly fifteen minutes of exercise with the equipment, using direct one-to-one correspondences in place of the transformations Ω_1 and Ω_2. After this initial practice, there was a rest interval, the transformations Ω_1 and Ω_2 were presented visually, and S was asked to memorise them. (As Diagram 4 shows, a visual image of the two transformations was displayed throughout the experiment, but no subject seemed to pay any attention to this material, and nobody had any difficulty in recalling the form of the transformations when asked to do so.) At this point, the main part of the experiment commenced, and continued until S had achieved the terminal performance criterion.

MAIN RESULTS

The T values for each subject are shown in Table 1. If Jonkheere's (1954) trend test is applied to the three sets of data, the null hypothesis (of no trend) can be rejected at the ·5 per cent level of significance ($p <$ ·005). The experimental prediction is therefore well supported.

Table 2 exhibits more detailed information about the four subjects who are marked with an asterisk * in Table 1. The value of n is split up into thirty-trial blocks. For each block, the table records the number of correct responses and the total number of responses that are associated with states defined by conjoint values of m_i and i.

It is evident from Table 2 that subjects acquire the skill in very different ways, even though their behaviour is contingent upon the simplification and alternation strategies of M. Subject *a* (and possibly *b* also) appears to learn the skill as a whole. Subjects *a* and *b* each receive about the same co-operative assistance from M in respect of subskill 1 and subskill 2. On the other hand, subjects *c* and *d* seem to learn one subskill at a time, even though the M strategies impose a modicum of joint rehearsal. It is evident that these subskills do interfere with one another, and it is also plain that there *can* be some positive transfer of training between one subskill and the other. The fact that the T values for *a* and *b* are lower than the T values for *c* and *d* suggests that the former subjects have made use of principles common to the

TABLE 1

NUMBER OF TRIALS REQUIRED TO REACH CRITERION PERFORMANCE

Condition A	*Condition B*	*Condition C*
TA = 150*	TB = 180	TC = 130
170	210	140
190	220	150
190	230	190
220	250	240
220	270	290
250	310	320
260	330	320
260	350	360
270*	350	390
290	370	430
290	370	430
290	370	450
300*	390	470
310	410	490
310	420	500
330	440	510
360*	460	510
380	460	530
440	470	570

Jonckheere's test of the null hypothesis, against the ordered a priori alternative of $TC > TB > TA$ permits the null hypothesis to be rejected (in favour of the expected trend) at the 0·5% level of significance.

TABLE 2

STIMULUS AND CORRECT RESPONSE DISTRIBUTIONS SAMPLED EACH 30 TRIALS, FOR 4 SUBJECTS, a, b, c and d, WHO ACHIEVED THE TERMINAL CRITERION CONDITION IN 150, 270, 300 AND 360 TRIALS. IN THE STATE, i(n), mi(n) THE ENTRY IS X/Y, WHERE X = NUMBER OF CORRECT RESPONSES AND Y = NUMBE OF STIMULI DELIVERED.

Trial	πi type	m=1	m=2	m=3	m=1	m=2	m=3	m=1	m=2	m=3	m=1	m=2	m=3
1 to	1	9/9	5/5	1/2	7/8	7/7	0/1	8/8	5/5	0/0	10/11	7/10	0/0
30	2	8/8	4/5	0/0	9/10	2/4	0/0	4/17	0/0	0/0	2/9	0/0	0/0
31 to	1	0/0	5/6	4/9	0/0	1/1	8/9	0/0	9/10	6/14	1/1	5/14	0/1
60	2	0/0	8/11	2/4	0/0	5/15	1/5	4/10	0/0	0/0	9/13	0/0	0/0
61 to	1	0/0	6/7	3/6	0/0	8/9	3/3	0/0	3/4	7/13	6/9	2/10	0/0
90	2	0/0	4/6	8/11	0/0	8/9	3/9	4/13	0/0	0/0	5/7	3/4	0/0
91 to	1	0/0	0/0	12/17	0/0	1/1	7/9	0/0	0/0	9/13	4/4	8/14	0/0
120	2	0/0	2/2	9/13	0/0	10/14	3/6	9/17	0/0	0/0	1/1	1/11	0/0
121 to	1	0/0	0/0	17/17	0/0	0/0	12/15	0/0	0/0	8/11	0/0	12/22	0/0
150	2	0/0	0/0	12/13	0/0	2/2	6/13	10/14	0/5	0/0	0/0	2/7	0/1
151 to	1	Subject given 50			0/0	0/0	9/11	0/0	0/0	6/9	0/0	6/7	0/3
180	2	trials; $\pi i=0{\cdot}5$			0/0	0/0	14/19	3/4	9/17	0/0	0/0	12/18	0/2
181 to	1	for terminal cri-			0/0	0/0	14/15	0/0	0/0	9/17	0/0	11/15	0/5
210	2	terion test			0/0	0/0	11/15	1/1	8/12	0/0	0/0	5/5	2/3
211 to	1				0/0	0/0	14/16	0/0	0/0	8/11	0/0	9/12	1/8
240	2				0/0	0/0	10/14	0/0	6/8	8/11	0/0	1/1	4/9
241 to	1				0/0	0/0	14/15	0/0	0/0	11/12	0/0	4/7	5/14
270	2				0/0	0/0	15/15	0/0	1/1	13/17	0/0	0/0	4/9
271 to	1				Subject given 50			0/0	0/0	14/14	0/0	6/10	2/8
300	2				trials; $\pi i=0{\cdot}5$			0/0	0/0	15/16	0/0	2/2	5/12
301 to	1				for terminal cri-			Subject given 50			0/0	3/4	5/9
330	2				terion test			trials; $\pi i=0{\cdot}5$			0/0	2/2	9/15
331 to	1							for terminal cri-			0/0	1/1	18/18
360	2							terion test			0/0	0/0	10/11
											Subject given 50		
											trials; $\pi i=0{\cdot}5$		
											for terminal cri-		
											terion test		

pair of transformations—*i.e.*, they have achieved a useful transfer of training.

Since the man-machine system is dynamically stable, it is legitimate to derive steady-state measurements which may usefully characterise the behaviour of a subject (contingent upon the activity of M). The simplest measure of this sort is the relative amount of assistance provided in respect of subskill 1 and subskill 2. This is the sort of measurement proposed by Vygotsky, some thirty years ago, when he suggested that learning ability might be indexed in terms of the amount (and type) of help that the student needs in order to reach some criterion of proficiency.

In the present case it is possible to define the amount of relative assistance, A, as:

$$A = \frac{\text{Number of trials spent rehearsing subskill 1}}{\text{Total number of trials}}$$

where it is understood that trials at the "fully proficient" level, m = 3, are excluded from consideration. (This exclusion is rational since, for one of the subskills, much of the practice at m = 3 may simply be updating the subject's ability whilst the other subskill is being learned.)

The values of A for subjects *a*, *b*, *c*, and *d* are:

$A_a = 0{\cdot}46$, $A_b = 0{\cdot}32$, $A_c = 0{\cdot}12$, and $A_d = 0{\cdot}21$

If the subject learns the skill "as a whole," then A should approach the value of 0·5 (assuming that the subskills are of roughly equivalent difficulty in the overall population). On the other hand, if he learns "sequentially" (*i.e.*, one subskill after the other) there should be a bias, and A will exceed or fall short of 0·5 according to whether subskill 1 or subskill 2 is given precedence. Disregarding this precedence, a rough indication of sequential learning is $| A - 0{\cdot}5 |$. This is the absolute value of the difference between A and the value that A would have assumed if the skill had been learned as a whole. Values of this function, B (say), are:

$B_a = 0{\cdot}04$, $B_b = 0{\cdot}18$, $B_c = 0{\cdot}38$, and $B_d = 0{\cdot}29$.

These values suggest that only subject *a* learns as a whole. Subjects *b*, *c*, and *d* are grouped together as more or less sequential learners.

ACKNOWLEDGMENTS

The research reported in this paper has been sponsored by the Air Force Office of Scientific Research, O.A.R., under Contract AF 61(052)-640, with the European Office of Aerospace Research, U.S. Air Force; and by the Aeronautical Systems Division of the Air Force Systems Command, U.S.A.F., through the European Office of the Office of Aerospace Research, under Contract AF 61(052)-402, and was carried out at System Research Ltd.

REFERENCES

FELLER, W. (1957) *An Introduction to Probability Theory and its Applications* (2nd ed.). New York. Wiley.

JONCKHEERE, A. R. (1954) "A test of the significance for the relation between *m* rankings and *k* ranked categories." *Br. J. statist. Psychol.*, 7.

LEWIS, B. N. (1963a) "Adaptive teaching machines." *Programmed Learning*, **1**, 3–4.

LEWIS, B. N. (1963b) The rationale of adaptive teaching machines. In M. GOLDSMITH (ed.): *Mechanisation in the Classroom.* London. Souvenir Press.

LEWIS, B. N. (1963c) The adaptive control of small groups. In B. DODD (ed.): *Programming '63.* Sheffield University. Department of Education.

LEWIS, B. N., and PASK, G. (1964) "The development of communication skills under adaptively controlled conditions." *Programmed Learning*, **1**, 69–88.

LEWIS, B. N., and PASK, G. (1965) The theory and practice of adaptive teaching systems. In R. GLASER (ed.): *Teaching Machines and Programed Learning, II, Data and Directions.* Washington. National Education Association.

PASK, G. (1957) "A teaching machine for radar training." *Automation Progress*, 214–217.

PASK, G. (1958) Teaching machines. *Proceedings 2nd Congr. Int. Association Cybernetics, Namur* 1958. Paris. Gauthiers Villars.

PASK, G. (1960) "The teaching machine as a control mechanism." *Trans. Soc. Instrument Technology*, 72–89.

PASK, G. (1961) *An Approach to Cybernetics.* London. Hutchinsons.

PASK, G. (1962) Interaction between a group of subjects and an adaptive automaton to produce a self-organising system for decision-making. In M. C. YOVITS, G. T. JACOBI, and G. D. GOLDSTEIN (eds.): *Self-Organizing Systems—1962.* Washington D.C. Spartan Books.

PASK, G. (1963) A proposed experimental method for the behavioural sciences. In P. SCHADE and N. WEINER (eds.): *Progress in Biocybernetics, Vol,* 1. Amsterdam. Elsevier Press.

Pask, G. (1964) "Adaptive teaching systems," *Cybernetica*, 2.

Pask, G. (1965) Teaching as a control engineering process. *Control*, January, February, March, April 1965.

Pask, G. (1965b) Comments on the organisation of man, machines and concepts. In Heilprin, Markusson, and Goodman (eds.): *Education for Information Science*. London. Macmillan.

Pask, G. (1966) Man as a system that needs to learn. In D. Stewart (ed.): *Automaton Theory and Learning Systems*. New York. Academic Press.

Pask, G., and Lewis, B. N. (1964) Research on the design of adaptive teaching systems with a capability for selecting and altering criteria for adaptation. U.S.A.F. Contract AF 61(052)-402. *Annual Summary Report No.* 4.

Pask, G., and Mallen, G. L. (1965) The method of adaptively controlled psychological learning experiments. *Proceedings IFAC Symposium on Adaptive Control.* Instr. Soc. America (in press).

Vygotsky, L. S. (1962) *Thought and Language*. New York. Wiley.